

# Wireless Capacitive Pressure Sensor Operating up to 400°C from 0 to 100 psi Utilizing Power Scavenging

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**Abstract** — In this paper, a wireless capacitive pressure sensor developed for the health monitoring of aircraft engines has been demonstrated. The sensing system is composed of a Clapp-type oscillator that operates at 131 MHz. The Clapp oscillator is fabricated on an alumina substrate and consists of a Cree SiC MESFET, thin film inductor, Compex chip capacitors and Sporian Microsystem capacitive pressure sensor. The resonant tank circuit within the oscillator is made up of the pressure sensor and a spiral thin film inductor, which is used to magnetically couple the wireless pressure sensor signal to a coil antenna placed over 1 meter away. 75% of the power used to bias the sensing system is generated from thermoelectric power modules. The wireless pressure sensor is operational at room temperature through 400°C from 0 to 100 psi and exhibits a frequency shift of over 600 kHz.

**Index Terms** — Capacitive pressure sensor, wireless transmission, high temperature, SiC, Oscillator .

## I. INTRODUCTION

Sensing capabilities for harsh environments is growing at an unprecedented rate. The need for sensors to be positioned as close as possible to the harsh environment is critical for accurate measurements in real time. Many of these circumstances require electronics that can function at high temperatures. Currently, the largest user of high-temperature electronics is the downhole oil and gas industry. In the past, drilling operations were at maximum temperatures of 150°C to 175°C, but declining reserves of easily accessible natural resources coupled with the advances in technology have motivated the industry to drill deeper and, as a result, the electronics must operate as high as 300°C [1]. The automotive industry is another field where high temperature electronics are widely used. The need to locate sensors, signal conditioning and control electronics closer to the heat sources will be an essential requirement [2]. Cylinder pressure temperatures are monitored up to 300°C and exhaust sensing can be as high as 850°C. Aircraft engines that use intelligent controls and health monitoring require a variety of sensors [3,4]. Many of the sensors operate at temperatures through 500°C and above and require electronics that can function at these temperatures to assure essential health monitoring [5,6]. In this paper, a wireless pressure sensor for high temperature operation has been demonstrated. The pressure sensor was

characterized at room temperature (25°C) and 400°C from 0 to 100 psi in steps of 10 psi. The sensor circuit operates at 131MHz and is functional up to 400°C.

## II. PRESSURE SENSOR DESIGN

The capacitive micro-electromechanical systems (MEMS) pressure sensor was developed by Sporian Microsystem. One electrode of the capacitive sensor is fabricated on the deflecting chamber membrane and the second electrode is on the fixed SiCN substrate forming a sealed chamber. The sealed cavity is flip-chip bonded onto a SiCN substrate with gold (Au) contacts and is shown in Fig. 1.

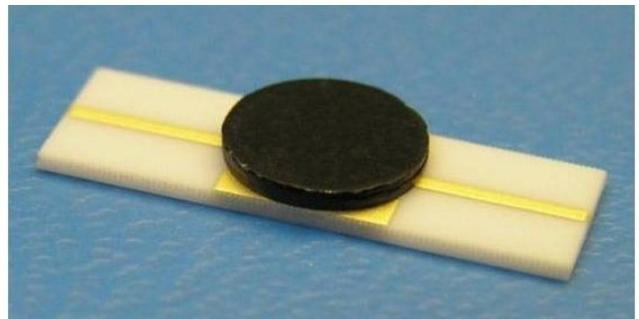


Figure 1: Sporian Microsystem capacitive pressure sensor.

The Sporian Microsystem pressure sensor was characterized with an Agilent B1500A Semiconductor Device Analyzer and a high temperature/pressure chamber. The Semiconductor Device Analyzer was calibrated to the leads of the pressure sensor inside the high temperature pressure chamber at room temperature to remove the effects of the chamber and cabling. The pressure sensor capacitance was measured at 1 MHz from 0 to 100 psi at 25°C and 400°C and the results are shown in Fig. 2.

At 25°C, the sensor has an initial capacitance of 4.0993 pF at 0 psi and reduces to 3.2250 pF at 100 psi, which is a  $\Delta C$  of 0.8743 pF. At 400°C, the sensor has a capacitance of 4.2403 pF at 0 psi and 3.3459 pF at 100 psi, which is a  $\Delta C$  of 0.8944 pF. The capacitance increases by 3% from 25°C to 400°C, which may be due to the inability to calibrate at the higher temperatures. However the change

in capacitance from 0 to 100 psi at both 25 and 400°C is basically the same, indicating that the sensor is consistent over the temperature range.

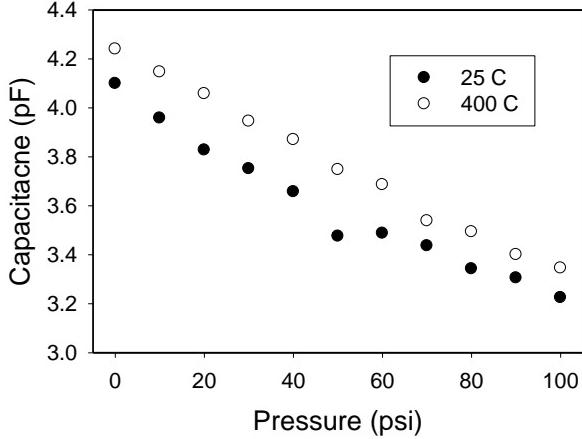


Figure 2: Sporian pressure sensor measured from 0 to 100 psi at 25 and 400°C.

### III. WIRELESS PRESSURE SENSOR DESIGN AND FABRICATION

The wireless pressure sensor is composed of a Clapp-type oscillator design where more information on the design methodology can be found in [7] and the circuit schematic is shown in Fig. 3. A Cree CRF24010D SiC MESFET is the active device used in this system. The values for  $L_T$ ,  $C_1$  and  $C_2$  are 500 nH, 14 pF and 28 pF, respectively.  $L_T$  is a 2-turn thin film spiral inductor, which is also used to provide magnetic coupling for wireless signal transmission.  $C_1$  and  $C_2$  are Compex chip capacitors.  $C_1$  is a single chip capacitor with a value 14 pF and  $C_2$  is two chip capacitors in parallel to achieve the 28 pF value.  $C_T$  is the Sporian pressure sensor. The wireless pressure sensor was designed to operate at 130 MHz. The design frequency was chosen based on current availability of chip capacitors, but it can easily be modified for other oscillating design frequencies.

The wireless sensing system was fabricated on alumina CoorsTek Superstrate 996 with a dielectric constant of 9.9 and a substrate thickness of 500  $\mu\text{m}$ . The metallization consists of a Ti/Au (0.15/1.7  $\mu\text{m}$ ) layer, which was deposited using thin film microfabrication processing techniques. Wire bonds were used to make electrical connections between components and pads. A photograph of the circuit is shown in Fig. 4.

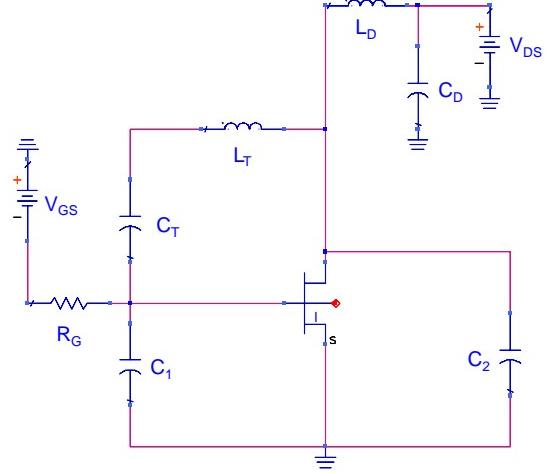


Figure 3: Schematic of wireless sensor.

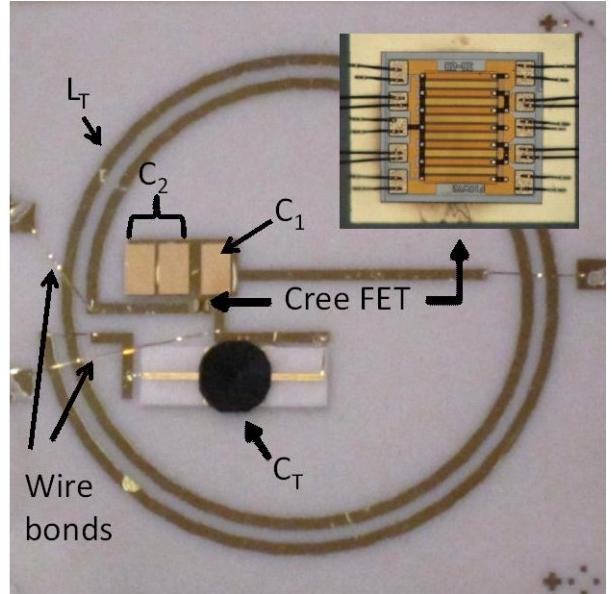


Figure 4: Photograph of the wireless pressure sensor.

### IV. POWER SCAVENGING

Thermoelectric power scavenging was used to provide partial power to bias the wireless pressure sensor. The high temperature thermoelectric generators (TEG) were composed of silicon germanium. The electrodes were composed of copper on the cold end of the device and nickel foil on the hot end. A heat source was used to warm the hot end to 185°C and a cold source chilled the cold end to 19°C, for a temperature differential of 166°C.

The transistor drain voltage,  $V_{DS}$ , was held constant at 10 V and the drain current,  $I_{DS}$ , was held constant at 90 mA. Approximately 2.7 V was supplied by a DC power supply to the drain and the rest from the TEGs.

## V. MEASUREMENT PROCEDURE AND RESULTS

A high temperature/pressure chamber developed at NASA Glenn Research Center was used to heat and pressurize the wireless pressure sensor up to 400°C and 100 psi. The chamber was fitted with feed-throughs so biasing can be applied and the temperature can be monitored at several different locations throughout the chamber. The signal was transmitted to a 20 turn, 20 cm diameter wire pickup coil over a distance of approximately one meter away. The coil was connected to an Agilent E4440A Series Spectrum Analyzer where the data was recorded.

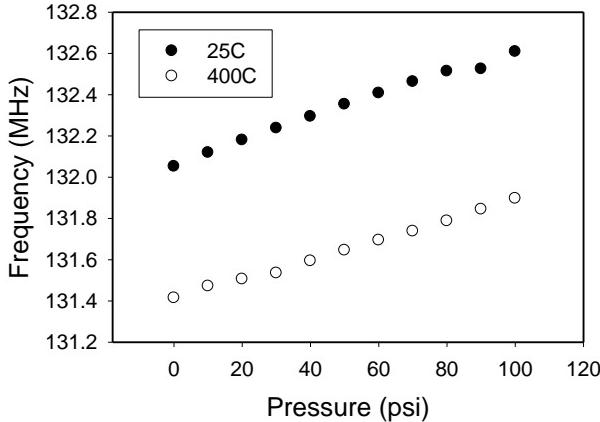


Figure 5: Wireless pressure sensor pressure frequency vs. pressure at 25°C and 400°C.

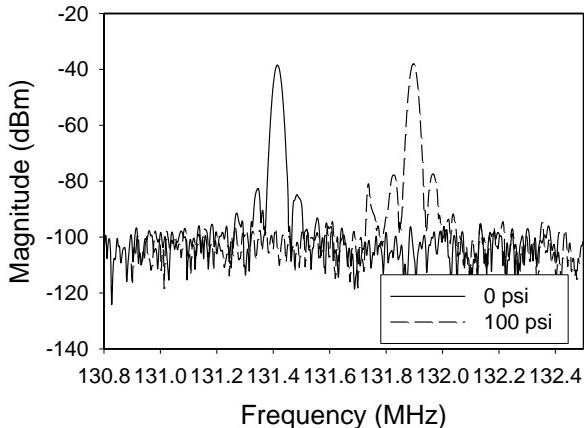


Figure 6: Wireless pressure sensor pressure spectrum response from 0 to 100 psi at 400°C.

The wireless pressure sensor was characterized at 25°C and 400°C from 0 to 100 psi in steps of 10 psi and the results are shown in Fig. 5. The wireless sensor resonant frequency increased as the pressure sensor capacitance decreased with increasing pressure, as expected. Furthermore the resonant frequency of the wireless sensor was greater at 25°C than at 400°C due to the slight increase in pressure sensor capacitance at the higher

temperatures. Fig. 6 shows the spectrum response of the wireless sensor for 0 and 100 psi at 400°C. The data indicates that from 0 to 100 psi there is a resonant frequency shift of over 600 kHz.

## VI. CONCLUSION

A wireless capacitive pressure sensor developed for health monitoring of aircraft engines and other high temperature applications has been demonstrated. The performance of the pressure sensor used in this system was consistent from 25 to 400°C with only a slight increase in capacitance over the temperature range due to a calibration error. The wireless pressure sensor operates at 131 MHz and had a linear response from 0 to 100 psi at both 25 and 400°C. The wireless system exhibited a frequency shift of over 600 kHz from 0 to 100 psi, indicating it is a good candidate for monitoring pressure in aircraft engines.

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